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STAGE EQUIPMENT AND PROJECTION OPTICS EQUIPMENT

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INVENTOR(s): KANEKO KENICHIRO
APPLICANT(s): NIKON CORP [000411] (A Japanese Company or Corporation), JP (Japan)
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ABSTRACT

PROBLEM TO BE SOLVED: To improve measurement accuracy in various types of measurement wherein a stage shifts.

SOLUTION: When a sample base 20 shifts integrally with a stage 18, the coordinate position of the sample base 20 is measured by a measuring means 26. A storing means 36 stores positional fluctuation of the sample base 20 in the Z axis direction generated by shift of the stage 18, corresponding to the coordinate position of the sample base 20. Therefore, in the case of, for example, measuring flatness of a sample W on the sample base 20, while shifting the stage 18, the positional fluctuationin the Z axis direction corresponding to the coordinate position is read out from a storing means 36, by shifted position of the sample base 20, namely, by measuring point. The fluctuation is used as correction value, the position of the sample base 20 in the Z axis direction can be corrected, and flatness is measured under the corrected condition.
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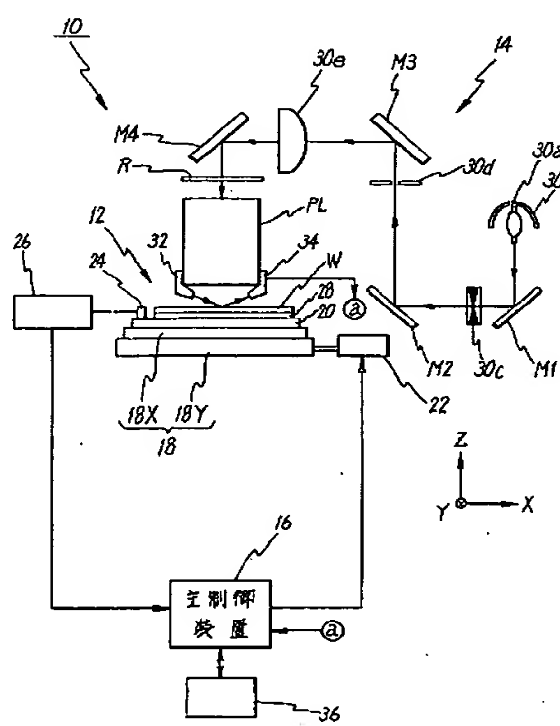
(71)出願人　000004112
株式会社ニコン
東京都千代田区丸の内３丁目２番３号
(72)発明者　金子　謙一郎
東京都千代田区丸の内３丁目２番３号　株式会社ニコン内
(74)代理人　弁理士　立石　篤司　（外１名）

(54)【発明の名称】　ステージ装置及び投影光学装置

(57)【要約】
【課題】　ステージの走りを基準として行われる種々の測定において、測定精度の向上を図る。
【解決手段】ステージ１８と一体的に試料台２０が移動すると、計測手段２６により試料台２０の座標位置が計測される。記憶手段３６には、ステージ１８の移動の際に生ずる試料台２０のＺ軸方向の位置の変動量が試料台２０の座標位置と対応付けて記憶されている。従って、ステージ１８を移動させながら試料台２０上の試料Ｗのフラットネス測定を行なう場合等に、試料台２０の移動位置、即ち各計測点毎に、記憶手段３６からその座標位置に対応するＺ軸方向の位置の変動量を読み出すことにより、その変動量を補正値として用い、試料台２０のＺ軸方向の位置を補正することが可能となり、この補正された状態でフラットネスの測定を行なうことが可能になる。



【特許請求の範囲】
【請求項１】　所定平面内を直交２軸方向に移動可能な第１ステージと；前記第１ステージ上に搭載され前記所定平面に直交する第１軸方向に微動可能な試料台と；前記第1ステージ上に搭載された前記試料台の前記２軸方向の座標位置を計測する計測手段と；前記第１ステージの移動の際に生ずる前記試料台の前記第１軸方向の位置の変動量を前記試料台の座標位置と対応付けて記憶する記憶手段とを有するステージ装置。
【請求項２】　前記記憶手段に記憶されたデータは、前記第１ステージを前記所定平面内でステップ移動させせつつ計測された、前記試料台上に搭載された平行平面表面ミラー板表面の計測点毎の所定の基準点からの前記第１軸方向の距離データに基づいて算出されたデータであることを特徴とする請求項１に記載のステージ装置。
【請求項３】　前記第１ステージの移動時に、前記試料台位置に対応する前記第１軸方向の位置の変動量のデータに応じて前記試料台の前記第１軸方向の位置を調整する調整手段を更に有することを特徴とする請求項１又は２に記載のステージ装置。
【請求項４】　前記第１ステージが、前記記憶手段に対応するデータが存在しない位置に移動されたとき、前記記憶手段内に存在するデータを用いて補完演算を行なってそのときの試料台位置に対応する前記試料台の前記第１軸方向の位置の変動量を算出する演算手段を更に有することを特徴とする請求項１ないし３のいずれか一項に記載のステージ装置。
【請求項５】　露光光によりパターン原板を照明し、このパターン原板上のパターンの像を投影光学系を介して感光基板上に投影する投影光学装置であって、
請求項１ないし４のいずれか一項に記載のステージ装置を前記感光基板の位置決め用ステージとして具備することを特徴とする投影光学装置。
【発明の詳細な説明】
【０００１】
【発明の属する技術分野】本発明は、ステージ装置及び投影光学装置に係り、更に詳しくは、少なくとも３自由度で試料を位置決め可能な試料台を備えたステージ装置及びこのステージ装置を試料の位置決めステージとして具備する投影光学装置に関する。ここで、投影光学装置としては、半導体素子や液晶表示基板をフォトリソグラフィ工程で製造する際に用いられる投影露光装置（例えば、ステッパー）やこの投影露光装置に搭載される投影光学系（投影レンズ）の諸収差を測定するレンズ検査装置が代表的に挙げられる。
【０００２】
【従来の技術】従来より、半導体素子や液晶表示基板をフォトリソグラフィ工程で製造する際には、露光光によりマスク又はレチクル（以下、「レチクル」と総称する）を照明し、レチクルのパターンを投影光学系を介して感光基板上に転写する投影露光装置が用いられている。また、この投影露光装置に搭載される投影光学系の諸収差の測定には、感光基板上にレチクルパターンを投影露光して、その露光結果（感光基板上に形成されたパターン像）を分析することにより投影光学系の諸収差を測定するレンズ検査装置が用いられている。
【０００３】これらの装置では、表面に感光材が塗布された試料としてのウエハ又はガラスプレート等の基板（以下、適宜「ウエハ」という）の位置決め用としてステージ装置が用いられている。この種のステージ装置としては、２次元平面（通常ＸＹ平面）内で移動するＸＹステージ、及びこのＸＹステージ上に搭載され、試料としてのウエハを保持してＸＹ平面に直交するＺ軸方向に移動する試料台（Ｚステージ）とを備えたものが、一般的である。
【０００４】例えば、ステップ・アンド・リピート方式の縮小投影型露光装置（いわゆるステッパー）では、ウエハのステッピングと露光を繰り返すことにより、ウエハ上の全面（全ショット領域）にレチクルパターンが転写される。このウエハのステッピングは、ＸＹステージの移動により行われる。
【０００５】ところで、最近における回路パターンの微細化に伴い、露光装置の性能として、重ねあわせ精度の向上は勿論、ますますの高解像力が要求されるようになってきた。しかるに、従来の縮小投影型露光装置では、大きな開口数（Ｎ．Ａ．）を有する投影レンズ系が用いられていることから、焦点深度が非常に小さく、ウエハ表面を投影光学系の基板側像面に一致させるための機構（例えばオートフォーカス機構、レベリング機構等）が必要不可決であるとともに、ウエハの場所による微妙な凹凸を測定すること、すなわちウエハフラットネス測定も必要となってきた。また、投影光学系の諸収差（例えば焦点深度、像面湾曲、像面傾斜等）を正確に計測する必要も生じてきた。
【０００６】
【発明が解決しようとする課題】上述したウエハフラットネス測定やレンズ検査装置によるレンズの諸収差の測定は、ステージの走りを基準として行われている。すなわち、ウエハフラットネス測定の場合、上述したＸＹステージを駆動して予め定められたマトリクス状の計測点にウエハを順次位置決めして、計測点毎にウエハ表面のＸＹステージの移動面に直交するＺ方向（通常は投影光学系の光軸方向）の位置を計測することによりなされる。
【０００７】しかるに、ＸＹステージ（より正確にはＸステージ及び／又はＹステージ)によってウエハをＸＹ平面内で移動させたとき（すなわちステージを走らせたとき）、試料であるウエハ表面は、ステージのＸＹ平面内の位置によりＺ方向に浮き沈みする。これは、例えば、ステージの駆動機構を送りねじとモータによって構

成する場合、ステージの案内面の微小な凹凸、送りネジとステージとの接続部に生じるガタ、送りネジの歪み等によって生じる。

【０００８】このため、ステージの位置による浮き沈み量、すなわちステージの走り特性が、ウエハフラットネス測定結果及び、レンズの諸収差測定結果に、誤差として生じていたが、ヨーイング干渉計により計測されるウエハのヨーイングと異なり、このステージの走り特性（浮き沈み量）だけを測定することはできなかったため、この誤差を許容した測定が行われていた。

【０００９】しかしながら、最近における集積回路（ＩＣ）のより一層の高集積化に伴い、上述したステージの走り特性に起因する測定誤差が許容できなくなりつつあり、また次世代の６４ＭバイトのＤＲＡＭの製造の際には、上記の測定誤差が許容できなくなることは確実視されている。

【００１０】本発明は、かかる事情の下になされたもので、請求項１ないし２に記載の発明の目的は、ステージの走りを基準として行われる種々の測定において、測定精度の向上を図ることができるステージ装置を提供することにある。

【００１１】また、請求項３に記載の発明の目的は、上記請求項１及び２に記載の発明の目的に加え、測定時にステージの浮き沈みを補正することが可能なステージ装置を提供することにある。

【００１２】また、請求項４に記載の発明の目的は、請求項３に記載の発明に比べても、ステージの走りを基準とする測定精度を一層向上させることができるステージ装置を提供することにある。

【００１３】また、請求項５に記載の発明の目的は、ステージの走りを基準として行われる測定、例えば感光基板のフラットネス測定を高精度に行なうことができる投影光学装置を提供することにある。

【００１４】

【課題を解決するための手段】請求項１に記載の発明は、所定平面内を直交２軸（Ｘ，Ｙ）方向に移動可能な第１ステージ（１８）と；前記第１ステージ（１８）上に搭載され前記所定平面に直交する第１軸（Ｚ軸）方向に微動可能な試料台（２０）と；第１ステージ（１８）上に搭載された前記試料台（２０）の前記２軸方向の座標位置を計測する計測手段（２６）と；前記第１ステージ（１８）の移動の際に生ずる前記試料台（２０）の前記第１軸方向の位置の変動量を前記試料台（２０）の座標位置と対応付けて記憶する記憶手段（３６）とを有する。

【００１５】これによれば、第１ステージ（１８）と一体的に試料台（２０）が移動すると、計測手段（２６）により試料台（２０）の座標位置が計測される。一方、記憶手段（３６）には、第１ステージ（１８）の移動の際に生ずる試料台（２０）の第１軸方向の位置の変動量が試料台（２０）の座標位置と対応付けて記憶されている。

【００１６】このため、例えば、第１ステージ（１８）を移動させながら試料台（２０）上に搭載された試料（Ｗ）のフラットネス測定を行なう場合等に、試料台（２０）の移動位置、即ち各計測点毎に、記憶手段（３６）からその座標位置に対応する第１軸方向の位置の変動量を読み出すことにより、その変動量を補正値として用い、試料台（２０）の第１軸方向の位置を補正することが可能になり、この補正された状態でフラットネスの測定を行なうことが可能になる。あるいは、フラットネス測定完了後に、フラットネス計測結果（すなわち、各計測点における試料表面の基準点からの第１軸方向の位置の測定値）を補正しても良い。いずれにしても、フラットネス等の測定精度を向上させることが可能になる。同様の理由により、投影レンズの諸収差測定も高精度に行なうことが可能になる。

【００１７】この場合において、前記記憶手段（３６）に記憶されたデータは、予め計測された試料台（２０）の座標位置に応じた第１軸方向の変動量を示すデータであれば、いかなる計測方法で計測されたデータであっても良く、例えば、請求項２に記載の発明の如く、前記第１ステージ（１８）を所定平面内でステップ移動させつつ計測された、前記試料台（２０）上に搭載された平行平面表面ミラー板（３８）表面の計測点毎の所定の基準点からの前記第１軸方向の距離データに基づいて算出されたデータであっても良い。この場合、平行平面表面ミラー板（３８）表面もフィゾー干渉計等の面形状計測手段によって予め計測しておくことが望ましい。

【００１８】また、上記のフラットネス等の測定における補正は、従来と同様にフラットネス測定を行なった後、各計測点における計測データから対応する座標位置の補正値を減算することにより、行なっても良く、各計測点毎に補正値を用いてリアルタイムで試料台（２０）の第１軸方向の位置を補正するようにしても良い。後者の場合、請求項３に記載の発明の如く、第１ステージ（１８）の移動時に、そのときの試料台（２０）位置に対応する第１軸方向の位置の変動量のデータに応じて試料台（２０）の第１軸方向の位置を調整する調整手段（１６、２２）を更に設けることが望ましい。このようにすれば、試料台（２０）の第１軸方向の位置が、調整手段（１６、２２）により試料台（２０）の位置に対応するデータに応じて調整されるので、第１ステージ（１８）の浮き沈みがない状態と同様の理想的な状態で、フラットネス測定等を高精度に行なうことが可能となる。

【００１９】上記請求項１ないし３のいずれか一項に記載の発明において、請求項４に記載の発明の如く、第１ステージ（１８）が、記憶手段（３６）に対応するデータの存在しない位置に移動されたとき、記憶手段（３６）内に存在するデータを用いて補間演算を行なってそ

のときの試料台（２０）の位置に対応する試料台（２０）の第１軸方向の位置の変動量を算出する演算手段（１６）を更に設けることが望ましい。

【００２０】これによれば、記憶手段（３６）に対応するデータの存在しない位置に第１ステージ（１８）が移動した場合にも、演算手段（１６）によって試料台（２０）の位置に対応する第１ステージ（１８）の第１軸方向の位置の変動量が得られるので、記憶手段（３６）が有するデータ位置に限定されず、第１ステージ（１８）の可動範囲全域にわたって試料台（２０）の第１軸方向の位置の変動を補正、あるいは調整できるようになる。従って、上記請求項１ないし３に記載の発明に比べても一層フラットネス等の測定精度を向上させることが可能になる。また、この場合、記憶手段（３６）に予め記憶するデータが少なくても良くなるため、あまり多くの計測点での変動量の測定が不要となり、その分計測時間を短縮することができる。

【００２１】請求項５に記載の発明は、露光光によりパターン原板（Ｒ）を照明し、このパターン原板（Ｒ）上のパターンの像を投影光学系（ＰＬ）を介して感光基板（Ｗ）上に投影露光する投影光学装置であって、請求項１ないし３のいずれか一項に記載のステージ装置を前記感光基板の位置決め用ステージとして具備することを特徴とする。これによれば、請求項１ないし３のいずれか一項に記載のステージ装置を感光基板（Ｗ）の位置決め用ステージとして具備することから、当該ステージ装置により記憶手段（３６）内の各計測点での試料台（２０）の第１軸方向の位置の変動量データに基づいて試料台（２０）の第１軸方向の位置の補正、あるいはフラットネス等の測定値の補正が行なわれ、試料台（２０）上に載置された感光基板（Ｗ）の、例えばフラットネス測定の測定精度を向上させることができるようになる。同様の理由により、投影光学系の諸収差測定も高精度に行なうことが可能になる。

【００２２】

【発明の実施の形態】以下、本発明の一実施形態を図１ないし図４に基づいて説明する。

【００２３】図１には、本発明に係るステージ装置が適用された一実施形態の投影光学装置としての投影露光装置１０の概略構成が示されている。この投影露光装置１０は、感光基板としてのウエハＷが搭載されるウエハステージ１２、このウエハステージ１２の上方に配置された投影光学系ＰＬ、この投影光学系ＰＬの上方に配置されて不図示のレチクルホルダに保持されたパターン原板としてのレチクルＲ、このレチクルＲを露光光により照明する照明系１４、及び装置全体を統括的に制御する主制御装置１６等を備えている。

【００２４】ウエハステージ１２は、不図示のベース上をＹ軸方向（図１おける紙面直交方向）に移動するＹステージ１８Ｙと、このＹステージ１８Ｙ上をＹ軸に直交するＸ軸方向（図１における紙面左右方向）に移動するＸステージ１８Ｘとから成る第１ステージとしてのＸＹステージ１８と、Ｘステージ１８Ｘ上に搭載され、ＸＹ平面に直交するＺ軸方向に所定量（例えば１００μｍ）移動可能な試料台２０とを備えている。これらＹステージ１８Ｙ、Ｘステージ１８Ｘ及び試料台２０は、駆動部２２によってそれぞれの移動方向に駆動されるようになっている。ここで、Ｙステージ１８Ｙ、Ｘステージ１８Ｘの駆動方式としては送りねじとモータとの組み合わせが使用されている。また、試料台２０は不図示の駆動機構を介してＺ方向に駆動されるようになっており、この駆動機構と試料台２０とによってウエハＷをＺ駆動するＺステージが構成されている。なお、駆動機構の内部には試料台２０のＺ駆動量を計測する、例えばエンコーダが設けられており、駆動部２２では試料台２０をＺ駆動する際に、このエンコーダの計測値を参照する。

【００２５】前記試料台２０上には、移動鏡２４が固定されており、この移動鏡２４に対向して当該移動鏡２４に測長ビーム（レーザビーム）を投射してその反射光により試料台２０の位置を計測する位置計測手段としてのレーザ干渉計２６が配置されている。なお、実際には、試料台２０上にはＸ軸に直交する反射面を有するＸ移動鏡とＹ軸に直交する反射面を有するＹ移動鏡とが設けられ、これらに対応してレーザ干渉計もＸ軸位置計測用のＸ軸レーザ干渉計とＹ軸位置計測用のＹ軸レーザ干渉計とが設けられているが、図１ではこれらが代表的に移動鏡２４、レーザ干渉計２６として図示されている。従って、以下の説明では、レーザ干渉計２６によって移動鏡２４を介して試料台２０のＸＹ２次元座標位置が高精度、例えば０．０１μｍの分解能で計測されるものとする。このレーザ干渉計２６の計測値は主制御装置１６に供給されている。

【００２６】また、試料台２０上には、ウエハホルダ２８が載置され、このウエハホルダ２８上に試料としてのウエハＷが不図示のバキュームチャック等により吸着保持されている。

【００２７】前記照明系１４は、光源としての水銀ランプ３０ａ、楕円鏡３０ｂ、ミラーＭ１、Ｍ２、Ｍ３、Ｍ４、シャッタ３０ｃ、ブラインド３０ｄ、及びコンデンサレンズ３０ｅ等を含んで構成されている。ここでこの照明系１４の構成各部の作用を簡単に説明すると、水銀ランプ３０ａで発生した照明光は、楕円鏡３０ｂによりその第２焦点近傍に集光され、不図示の波長選択素子等を介して露光波長である例えば３６４ｎｍのｉ線のみが取り出され、ミラーＭ１で反射されてシャッタ３０ｃに至る。ここで、シャッタ３０ｃが開状態であるとこの照明光（露光光）はミラーＭ２、及び不図示のフライアイレンズ等から成る照度均一化光学系を介してブラインド３０ｄに至り、このブラインドを透過した照明光はミラーＭ３、不図示のリレーレンズ系、コンデンサレンズ３

０ｅ及びミラーＭ３を介してレチクルＲに照射される。この場合、不図示の照度均一化光学系の作用によってレチクル面は均一な照度で照明される。なお、ブラインド３０ｄはレチクルＲのパターン形成面と共役な位置に配置されており、このブラインド３０ｄの開口部の形状によってレチクルＲの照明領域の形状が規定される。

【００２８】レチクルＲは、不図示のレチクルホルダに保持されており、このレチクルＲは不図示の調整装置によりＸＹ平面内でその位置が調整可能な構造となっている。このレチクルＲの下面には、不図示の回路パターンが描画されているが、このパターン形成面は、前述したウエハＷ表面と光学的にほぼ共役になっている。

【００２９】前記投影光学系ＰＬは、その光軸方向がＺ軸方向に一致する状態で不図示の本体コラムに保持されている。この投影光学系ＰＬとしては、ここでは、両側テレセントリックで所定の縮小倍率β（βは例えば１／４又は１／５）を有するものが使用されている。このため、レチクルＲとウエハＷの位置合わせが行われた状態で、照明系１４からの照明光によりレチクルＲが照明されると、レチクルのパターンの縮小像が投影光学系ＰＬを介して表面にフォトレジストが塗布されたウエハＷ上に投影露光されるようになっている。

【００３０】また、投影光学系ＰＬの側方には、送光部３２と受光部３４とから成るいわゆる斜入射光式の焦点検出系が設けられており、この焦点検出系（３２、３４）によってウエハＷ表面の光軸方向位置（すなわち焦点ずれ量）が計測されるようになっている。この焦点検出系（３２、３４）の検出信号が主制御装置１６に供給されるようになっている。

【００３１】前記主制御装置１６は、ＣＰＵ（中央処理装置）、ＲＯＭ（リード・オンリ・メモリ）、ＲＡＭ（ランダム・アクセス・メモリ）等を含むマイクロコンピュータ（又はミニコンピュータ）から構成され、レーザ干渉計２６の計測値をモニタしつつＸＹステージ１８の位置制御を行なう他、ウエハフラットネス測定（これについては後述する）及び露光制御等の機能を有する。

【００３２】さらに、本実施形態の投影露光装置１０では、この主制御装置１６にハードディスク等の比較的大容量の記憶手段としての記憶装置３６が設けられている。この記憶装置３６内には、予め後述するようにして計測され、試料台２０のＸＹ座標位置と対応付けて記憶されたＸＹステージの走り特性、すなわち試料台２０のＸＹ平面内の位置に応じたＺ軸方向の位置の変動量のデータが記憶されている。この変動量のデータは、例えば後述するウエハフラットネス測定の際等に、主制御装置１６内のＣＰＵによって読み出され、駆動部２２を介してＺ軸方向位置の変動量を補正する場合等に利用される。

【００３３】次に、上述した記憶装置３６内に記憶されるＸＹステージ１８の走り特性の計測方法の一例について、図２ないし図４に基づいて詳述する。

【００３４】このＸＹステージ１８の走り特性の計測は、投影光学系ＰＬ及び焦点検出系（３２、３４）等を装置に搭載する前に行われる。図２には、この計測を行なう際の装置の構成が概略的に示されている。なお、この図２においては照明系１４も図示を省略している。

【００３５】図２において、試料台２０上にはウエハＷ及びウエハホルダ２８の代わりに表面の平面度の極めて高い基準用平行平面表面ミラー板３８が載置されている。また、この基準用平行平面表面ミラー板３８の上方（通常、投影光学系ＰＬ）が配置される位置には、Ｚ軸方向計測用のレーザ測長干渉計（以下、「Ｚ干渉計」という）４０がその計測方向がＺ軸方向となる状態で固定工具４２を介して不図示の本体コラムに固定されている。このＺ干渉計４０の計測値は、主制御装置１６に供給されるようになっている。

【００３６】ＸＹステージ１８の走り特性を計測する際には、主制御装置１６内のＣＰＵでは、ＲＯＭ内の所定のプログラムに従って、予め定めたマトリクス状配置の計測点で試料台２０のＸＹ平面内の位置に応じたＺ軸方向の位置の変動量を計測すべく、レーザ干渉計２６の計測値をモニタしつつ、ＸＹステージ２０を駆動部２２を介して所定ステップ間隔毎にＸＹ２次元方向に移動して順次位置決めする。そして、主制御装置１６では、各位置決め位置でＺ干渉計４０の計測値を取り込み、この計測値（基準点からのＺ軸方向の値）を各計測点位置のレーザ干渉計２６の出力であるＸＹ座標位置に対応付けて記憶装置３６内に記憶する。

【００３７】これにより、図３に概念的に図示されるようなＸＹステージ１８（試料台２０）の移動に伴う（移動位置に応じた）試料台２０の浮き沈みが、図４に示されるように、マトリクス状配置の各計測点（図４の点線格子の各交点）毎に計測され、各計測点に対応する試料台２０の移動位置に応じた試料台２０のＺ軸方向の位置の変動量のデータがそのときの座標位置データに対応付けて記憶装置３６内にテーブル形式等で格納される。

【００３８】なお、図４中の実線は、上記の計測の際の実際のＸＹステージ１８の浮き沈みの一例を視覚的に示したものである。

【００３９】ここで、図４中の点線格子の各交点に対応する計測点の間隔を短くして計測点数を増やして厳密にＸＹステージ１８の走り特性を計測することは可能であるが、計測に時間がかかり過ぎるという不具合が生じる。

【００４０】そこで、必要以上の計測点数の増加を防止すべく、計測した各計測点のデータを基に、主制御装置１６では、近似関数補間、直線補間、又はスプライン補間等の補間方法により計測点相互間を補完して、ＸＹステージ１８の移動範囲全域の試料台２０のＺ軸方向の位置の変動量のデータを求め、これを試料台２０の座標位

置と対応付けて記憶装置３６に格納するようにしても良い。このようにすれば、図４に実線で示されるような実際のＸＹステージ１８の浮き沈みに近似したデータを、測定に時間を掛けることなく、得ることが出来る。

【００４１】さらに、この場合において、基準用平行平面ミラー板３８表面の凹凸を、予めフィゾー干渉計等の面形状測定手段で測定しておき、記憶装置３６に各測定点のデータ、あるいは測定点のデータを補完したデータを記憶する際に、各データから対応する座標位置のフィゾー干渉計等で測定した凹凸のデータを減じた（あるいは加算した）データを記憶装置３６に記憶するようにすることが一層望ましい。このためには、フィゾー干渉計により計測する際も、上記のＸＹステージ１８上に基準用平行平面ミラー板３８を図２と同じ位置に載置した状態で、フィゾー干渉計で計測を行い、基準点からの座標データに対応付けて面形状データを記憶装置３６あるいはＲＡＭ内の所定領域に格納するようにすることが望ましい。

【００４２】次に、上述のようにして構成された本実施形態に係る投影露光装置１０におけるウエハフラットネス測定時の動作を図１に基づいて説明する。

【００４３】前述したステージの走り特性の計測時と同様に、主制御装置１６内ＣＰＵでは、ＲＯＭ内の所定のプログラムに従って、予め定めたマトリクス状配置の計測点でウエハフラットネスを計測すべく、レーザ干渉計２６の計測値をモニタしつつ、ＸＹステージ２０を駆動部２２を介して所定ステップ間隔毎にＸＹ２次元方向に移動して順次位置決めする。そして、主制御装置１６では各位置決め位置で焦点検出系（３２、３４）の出力を取り込む。その際に、焦点検出系（３２、３４）の出力の取り込みに先立って、記憶装置３６に記憶された、その時の試料台２０の座標位置、すなわちレーザ干渉計２６の計測値に対応するステージの走り特性のデータ（Ｚ軸方向の位置変動量）を検索し、このデータを補正量として駆動部２２に与え、試料台２０のＺ軸方向位置がＸＹステージ１８の浮き沈みの影響を受けないように試料台２０のＺ軸方向位置を調整する。ここで、レーザ干渉計２６の計測値に対応するステージの走り特性のデータを取り出すために記憶装置３６を検索する際に、主制御装置では、例えばその座標位置とこれに対応するＺ軸方向変動量のデータが格納されているアドレスとの関係を導く式、あるいはルックアップテーブル等を用いてデータの格納領域を絞り込んで検索を行なう。なお、検索方法はこれらの方法に限定されず、迅速に検索できる方法であれば良い。

【００４４】上記の試料台２０のＺ軸方向位置を調整した後、その時のレーザ干渉計２６の計測値に対応付けて焦点検出系（３２、３４）の出力値（デフォーカス信号）を記憶装置３６に格納する。

【００４５】これにより、各計測点で計測された、ＸＹステージ１８の浮き沈みの影響が除去された正確なウエハフラットネスデータが計測点の座標位置と対応付けて記憶装置３６内に例えばテーブル形式で格納される。

【００４６】この場合において、前述したステージの走り特性の計測点の間隔より、ウエハフラットネスの計測点の間隔が狭い場合には、記憶装置３６内にデータが存在しない移動位置に試料台２０が位置決めされるが、かかる場合には、主制御装置１６では、その時の座標位置近傍の試料台２０のＺ軸方向の位置の変動量のデータを用いて近似関数補間、直線補間、又はスプライン補間等の補間方法により、その座標位置の試料台２０のＺ軸方向の位置の変動量のデータをリアルタイムで求めた後、このデータを補正量として駆動部２２に与え、試料台２０のＺ軸方向位置がＸＹステージ１８の浮き沈みの影響を受けないように試料台２０のＺ軸方向位置を調整する。

【００４７】これまでの説明から明らかなように、本実施形態では、ウエハステージ１２、移動鏡２４、レーザ干渉計２６、駆動部２２、主制御装置１６及びメモリ３６によって本発明に係るステージ装置が構成されている。また、主制御装置１６によって演算手段が構成され、さらに駆動部２２と主制御装置１６によって調整手段が構成されている。

【００４８】以上説明したように、本実施形態に係る投影露光装置１０によると、ＸＹステージ１８の案内面の凹凸等に起因する試料台２０の移動に伴うＺ位置の変動（浮き沈み）をＸＹステージ１８（試料台２０）の移動時に記憶装置３６内のデータを用いて補正することができることから、例えば、ウエハフラットネス計測に際し、各計測点で補正がなされた状態でウエハフラットネスを焦点検出系（３２、３４）により計測することができるので、ウエハフラットネスを高精度に計測することが可能になる。従って、今後、半導体の高密度化に伴ってウエハフラットネスの測定精度の要求が高くなっても要求に対応することができる。

【００４９】なお、上記実施形態では、ウエハフラットネス測定について説明したが、これに限らず、ステージの走りを基準にして測定を行なう測定であれば、本発明のステージ装置は、その計測の精度を向上させることができる。例えば、テスト露光結果により投影光学系ＰＬの諸収差（焦点深度、像面湾曲、像面傾斜等）の測定を行なう場合にも、ウエハ表面の光軸方向位置を上記と同様に調整することによりその測定精度を向上させることができる。この意味から、投影光学系が載せ代え自在に構成された投影光学装置としてのレンズ検査装置に、本発明に係るステージ装置は好適に適用できる。

【００５０】なお、上記実施形態中では、記憶装置内のデータ、あるいはそのデータに補間演算処理をして得たデータを用いて、測定時にリアルタイムで試料台のＺ位置を調整（補正）する場合について説明したが、従来と

同様に、かかる調整をすることなく、例えばウエハフラットネス測定等を行い、その測定後に記憶装置内のデータを用いて、対応する座標位置の計測値を補正することによっても高精度なウエハフラットネス測定等が可能になる。

【００５１】

【発明の効果】以上説明したように、請求項１ないし２に記載の発明によれば、ステージの走りを基準として行われる種々の測定において、測定精度の向上を図ることができるという従来にない優れた効果がある。

【００５２】また、請求項３に記載の発明によれば、上記請求項１及び２に記載の発明の効果に加え、測定時にステージの浮き沈みを補正することができるという効果がある。

【００５３】また、請求項４に記載の発明によれば、請求項３に記載の発明に比べても、ステージの走りを基準とする測定の精度を一層向上させることができるという効果がある。

【００５４】また、請求項５に記載の発明によれば、ステージの走りを基準として行われる測定、例えば感光基板のフラットネス測定を高精度に行なうことができるという効果がある。

【図面の簡単な説明】

【図１】一実施形態に係る投影露光装置の概略構成を示す図である。

【図２】図１の記憶装置に記憶されるデータの計測時の装置構成を概略的に示す図である。

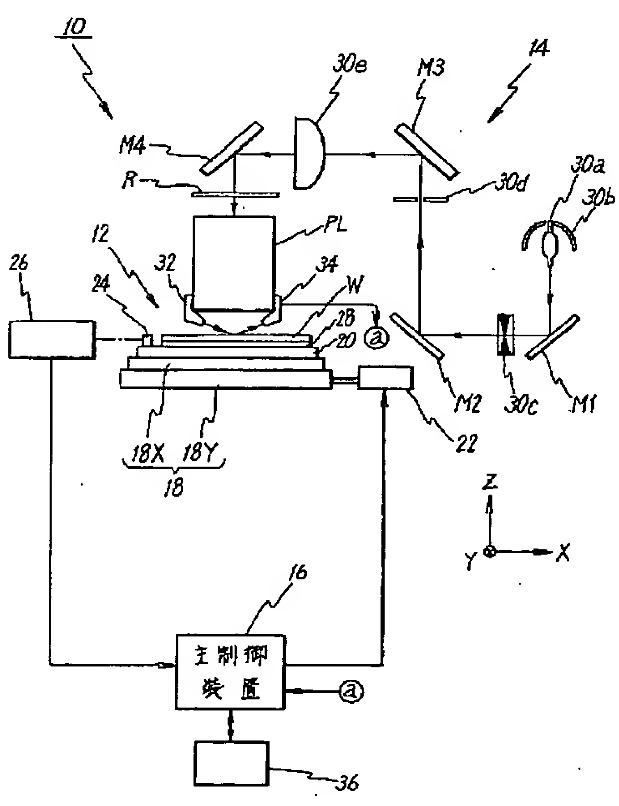
【図３】図１のＸＹステージをＹ軸方向に沿って移動させた際に生じる試料台のＺ軸方向の変位の一例を示す図である。

【図４】ＸＹステージをＹ軸方向に沿って移動させた際に生じる試料台のＺ軸方向の位置の変動の様子とともに、マトリックス状に配置された計測点を示す図である。

【符号の説明】

１０　投影露光装置（投影光学装置）
１６　主制御装置（調整手段の一部、演算手段）
１８　ＸＹステージ
２０　試料台
２２　駆動部（調整手段の一部）
２６　レーザ干渉計（計測手段）
３６　記憶装置（記憶手段）
３８　平行平面表面ミラー板
Ｒ　レチクル（パターン原板）
ＰＬ　投影光学系
Ｗ　ウエハ（試料、感光基板）

【図１】



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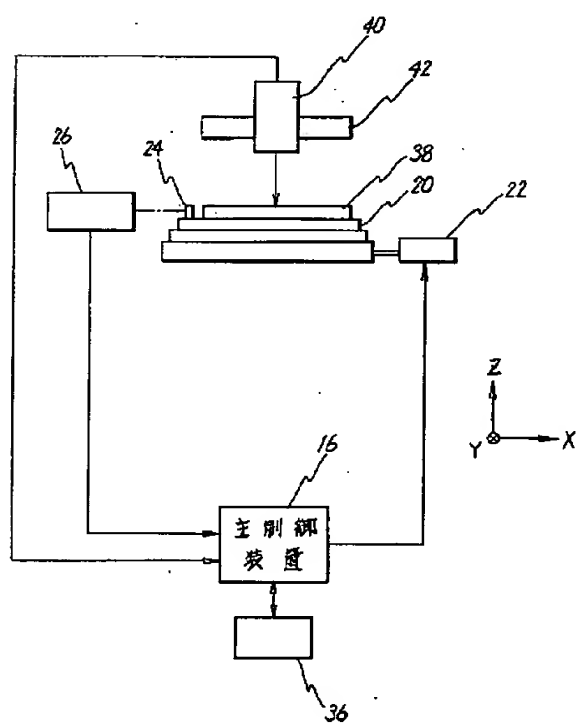

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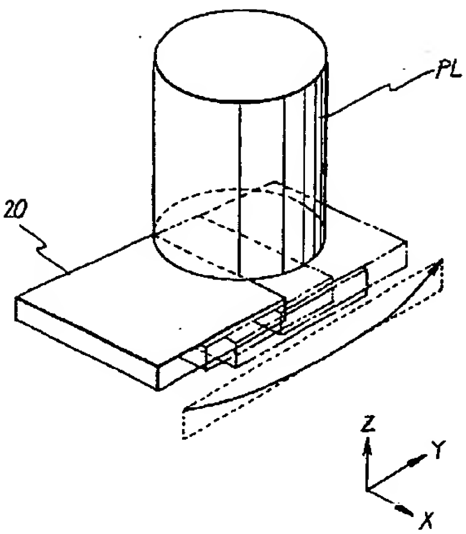

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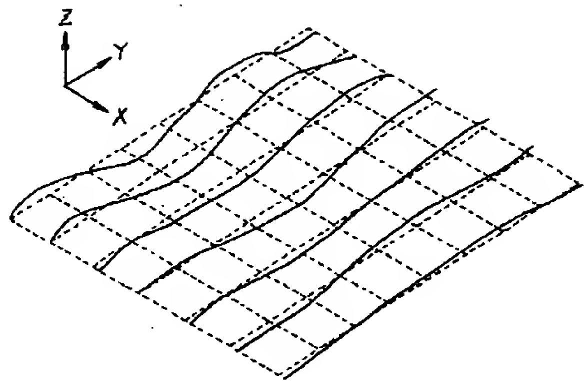


U.S. Patent Application
Serial No. 08/990,581
corresponding to JP Patent
Application Laid-Open No. 10-177950

STAGE APPARATUS AND PROJECTION OPTICAL APPARATUS

The present invention relates to a stage apparatus and a projection optical apparatus. More particularly, the present invention relates to a stage apparatus including a material support capable of positioning a material piece carried thereon with at least three degrees of freedom, and to a projection optical apparatus including such a stage apparatus used as a positioning stage for a material piece. One representative example of such a projection optical apparatus is a projection exposure apparatus, such as a stepper, for use in a photolithographic process forming a part of the fabrication process of semiconductor devices, liquid crystal displays or other products. Another example is lens inspection equipment for measuring various aberrations associated with a projection optical system (or projection lens) equipped for such a projection exposure apparatus.

In photolithographic process for fabricating semiconductor devices, liquid crystal displays or other products, there have been used various projection exposure machines in which an exposure light beam is used to illuminate a mask or a reticle (a generic term "reticle" is used to mean either hereinafter) so as to transfer a pattern formed on the reticle through a projection optical system onto a photosensitized substrate. Further, in order to measure aberrations associated with a projection optical system equipped for such a projection exposure machine, there has been used lens inspection equipment in which various aberrations with the projection optical system are measured by making a projection exposure so as to transfer an image of a reticle pattern onto a photosensitized substrate and analyzing the exposure result (or the resulting pattern image formed on the photosensitized substrate.)

With these machines and equipment, a stage apparatus is typically used for positioning a material piece or substrate having a photosensitive layer coated on its

surface. The substrate may typically comprise a silicon wafer or a glass plate (referred to simply as a "wafer" hereinafter). One common stage apparatus comprises an XY-stage capable of two-dimensional movement in a plane (typically, an XY-plane) and a material support (or Z-stage) for supporting a material piece or wafer thereon, the material support being mounted on the XY-stage and capable of displacing in the Z-direction perpendicular to the XY-plane.

By way of example, consider a demagnification projection exposure apparatus of the step-and-repeat type (commonly referred to as a "stepper"). In an exposure apparatus of this type, after the exposure of a shot-area, the wafer is moved or stepped to the next shot-area and the process is repeated until the entire surface of the wafer (or every shot-area on the wafer) has been processed to have reticle patterns transferred onto it. The stepping movement of the wafer is produced by the two-dimensional movement or translation of the XY-stage supporting that wafer.

With recent progress in the microminiaturization of circuit patterns exposure apparatuses are required to provide higher performance including an improved overlay accuracy as well as a higher resolution. Because a typical demagnification exposure apparatus uses a projection lens having a large numerical aperture (NA), its depth of focus is so small that a certain, appropriate mechanism must be provided for bringing with precision the surface of the wafer to a position at which it will be coincident with the image plane of the reticle pattern defined by the projection lens (such a mechanism may be, for example, an auto-focussing mechanism or a levelling mechanism). Also, it is desired to measure minute irregularities in the nominally flat surface of a wafer, or variation in height of the surface of a wafer placed on the stage among different points on the wafer surface. That is, wafer-flatness measurement is desired. Further, it is also desired to measure with accuracy various aberrations (such as, variation in depth of focus, curvature of image plane, tilt

of image plane and others) associated with a projection optical system.

Wafer-flatness measurement, as well as the measurement of aberrations with the projection lens by lens inspection equipment, have been typically performed by using the positions of the moving XY-stage as the reference for the measurement. Specifically, in the case of wafer-flatness measurement, the XY-stage is driven so as to sequentially move the wafer into a number of predetermined measurement points arranged in a rectangular array or matrix, and the height (or the position in the Z-direction) of the surface of the wafer is measured at each measurement point. The Z-direction is perpendicular to the plane in which the XY-stage moves and is usually defined as the direction along the optical axis of the projection optical system.

Unfortunately, the surface of the wafer or material piece carried by the XY-stage may rise and sink (or displace in the Z-direction) while the XY-stage is driven (or more exactly an X-stage and/or a Y-stage, together composing the XY-stage, are driven) to move the wafer in the XY-plane. In the case where the drive mechanism for the stage comprises a feed screw in threading engagement with the stage and an electric motor for rotating the feed screw, such displacement in the Z-direction may be possibly caused by various factors, including minute irregularities in the nominally flat bearing surface along which the stage is guided, an inevitable play between the feed screw and the stage engaging with each other, some distortion induced in the feed screw, and others.

Therefore, the rise/sink of the stage produced when the stage is moved into different positions, or the displacement characteristic of the stage, often causes errors in the results of the wafer-flatness measurement and the lens-aberration measurement. Further, unlike the yaw of wafers which may be separately measured with ease by a yaw-measuring interferometer, it has been impossible to separately measure the displacement characteristic of the stage (or the rise/sink of the stage), with the result that

the wafer-flatness measurement and the lens-aberration measurement have been performed so far, allowing for such errors.

Nevertheless, with the continuing increase in the complexity of present-day integrated circuits (ICs), the measurement errors caused by an undesirable displacement characteristic of the stage are becoming unacceptable, and it is almost certain that such measurement errors are not acceptable for the fabrication of the next generation of 64-megabit dynamic random access memories (DRAMs) any longer.

In view of the foregoing, it is an object of the present invention to provide a stage apparatus which may provide an improved measurement accuracy in various measurement processes in which the positions of the moving stage are used as a reference for the measurement.

It is another object of the present invention to provide a stage apparatus which is capable of correcting for the rise/sink of the stage during such a measurement process.

It is a further object of the present invention to provide a stage apparatus which may improve measurement accuracy with the positions of the moving stage being used as the reference for the measurement.

It is a yet further object of the present invention to provide a projection optical apparatus which is capable of performing various measurement processes in which the positions of the moving stage are used as the reference for the measurement, such as the flatness measurement of a substrate, with great precision.

In accordance with the present invention, there is provided a stage apparatus comprising: a first stage movable in two orthogonal directions in a predetermined plane; a material support mounted on the first stage and capable of minute displacement in the direction along a first axis perpendicular to the predetermined plane; a measuring device for measuring coordinates of the position of the material support mounted on the first stage in the two orthogonal directions; and a storage for storing displacement data

indicative of displacement of the material support in the direction along the first axis, as caused by movement of the first stage, in association with coordinates of corresponding position of the material support.

In this stage apparatus, when the material support is moved along with the first stage, the coordinates of the position of the material support are measured by the measuring device. At the same time, displacement of the material support in the direction along the first axis as caused by the movement of the first stage is stored in the storage in association with coordinates of corresponding position of the material support.

Therefor, when for example flatness measurement of a material piece placed on the material support is performed while the stage is moved, such displacement of the material support in the direction along the first axis that is indicated by the displacement data in the storage and corresponds to the current position of the material support at each measurement point, may be read out from the storage and used as correction amount for correcting the position of the material support in the direction along the first axis. Thus, the flatness measurement may be performed with the correction thus effected. Alternatively, after the flatness measurement process is completed, the results of the measurement (i.e., the measured distance of the surface of the material piece from a reference point, as measured in the direction along the first axis at each measurement point) may be corrected using the displacement data in the storage. In either case, the measurement accuracy of the flatness measurement process may be improved. For a similar reason, measurement of aberrations associated with a projection lens may be performed with high accuracy as well.

Further, with the stage apparatus above, the displacement data stored in the storage may be any of data indicative of displacements of the material support in the direction along the first axis corresponding to a number of positions of the material support, irrespective of the method of performing the measurement. More particularly,

the displacement data stored in the storage may be data as derived by arithmetic operation from a distance data indicative of a distance of a surface of a plane-parallel surface-mirror placed on the material support from a predetermined reference point, as measured in the direction along the first axis at each of measurement points while the first stage is moved with step intervals in the predetermined plane. In this case, it is preferable to measure, in advance, the flatness of the surface of the plane-parallel surface-mirror by an appropriate surface shape measuring device, such as a Fizeau interferometer.

In addition, correction to the results of the flatness measurement process may be effected after the flatness measurement process itself is completed as with a conventional correction method, by subtracting correction amount (derived from the displacement data stored) at the corresponding position in the predetermined plane, from the measured value at each measurement point. Alternatively, correction may be made by correcting the position of the material support in the direction along the first axis through a real-time correction operation using the correction amount just measured, during the flatness measurement process. In the latter case, it is preferable that the stage apparatus may further comprise an adjustor for adjusting, while the first stage is moved, the position of the material support in the direction along the first axis, depending on the amount of such displacement of the material support in the direction along the first axis that is indicated by the displacement data and that corresponds to the current position of the material support. In this arrangement, the position of the material support in the direction along the first axis may be corrected depending on the amount of such displacement of the material support that corresponds to the current position of the material support by means of the adjustor. Therefore, the flatness measurement process and other measurement processes may be performed under an ideal condition effectively with no rise/sink of the first stage, and thus with great precision.

Moreover, it is also preferable that the stage apparatus may further comprise an arithmetic operation device for performing interpolation on the displacement data in the storage to derive the amount of such displacement of the material support in the direction along the first axis that corresponds to the current position of the material support, when the first stage has been moved to such a position for which the displacement data in the storage contains no indication of displacement.

With this arrangement, even when the first stage has been moved to such a position for which the displacement data stored in the storage contains no indication of displacement, such displacement of the first stage in the direction along the first axis that corresponds to the current position of the material support may be derived by means of the arithmetic operation device. As the result, displacement of the material support in the direction along the first axis may be corrected, or eliminated by adjustment, not only at the positions of the first stage for which the displacement data in the storage contains indications of displacement, but also at any other positions of the first stage into which it may be moved. Thus, the measurement accuracy in the flatness measurement or other measurements may be further improved. In addition, this effectively reduces the number of necessary data values to be stored in advance in the storage, so that displacement measurement steps at reduced measurement points are sufficient for the purpose, resulting in a reduced time for the measurement procedure.

In accordance with the present invention, there is also provided a projection optical apparatus comprising: a stage apparatus for supporting a substrate; a mask having a pattern formed thereon; an illumination system for illuminating the mask with an exposure light beam; a projection optical system for projecting the pattern formed on the mask onto the substrate with the exposure light beam; and the stage apparatus having: a first stage movable in two orthogonal directions in a predetermined plane; a material

support for supporting a substrate, the material support being mounted on the first stage and capable of minute displacement in the direction along a first axis perpendicular to the predetermined plane; a measuring device for measuring coordinates of the position of the material support mounted on the first stage in the two orthogonal directions; and a storage for storing displacement data indicative of displacement of the material support in the direction along the first axis, as caused by movement of the first stage, in association with coordinates of corresponding position of the material support.

With the projection optical apparatus above, by virtue of provision of the stage apparatus for use as a stage for positioning the photosensitized substrate, correction may be effected to the position of the material support and/or the measured values obtained through the flatness measurement process and other measurement processes based on the displacement data stored in the storage and indicative of displacements of the material support in the direction along the first axis at a number of measurement points. Thus, the measurement accuracy with the flatness measurement process performed on the photosensitized substrate placed on the material support may be improved. For a similar reason, the measurement of aberrations with a projection lens may be performed with great accuracy as well.

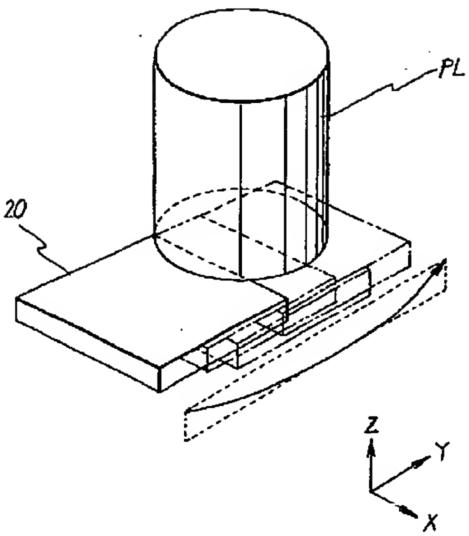
The above and other objects, features and advantages of the present invention will be apparent from the following detailed description of preferred embodiments thereof, reference being made to the accompanying drawings, in which:

Fig. 1 is a schematic of a projection exposure apparatus according to an embodiment of the present invention, showing an implementation thereof for exposure process;

Fig. 2 is a schematic of the apparatus of Fig. 1, showing an implementation thereof for data acquisition process for data to be stored in a storage device of Fig. 1;

Fig. 3 illustrates a typical displacement of the

【図３】



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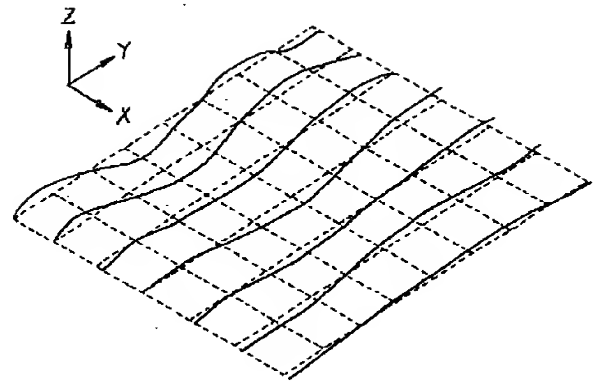

material support of Fig. 1 in the Z-direction as produced when the XY-stage of Fig. 1 is moved in the direction along the Y-axis; and

Fig. 4 illustrates a typical displacement of the material support as produced when the XY-stage is moved in the direction along the Y-axis, together with a number of measurement points arranged in a rectangular array or matrix.

Referring now to Figs. 1 to 4 of the accompanying drawings, preferred embodiments of the present invention will be described in detail.

Fig. 1 is a schematic of a projection exposure apparatus 10 according to an embodiment of the present invention, which is a representative of various projection optical apparatus with which a stage apparatus according to the present invention may be used. The projection exposure apparatus 10 includes a wafer stage 12 for carrying thereon a photosensitized substrate or wafer W, a projection optical system PL disposed above the wafer stage 12, a master matrix of a pattern or reticle R held on a reticle holder (not shown) and disposed above the projection optical system PL, an illumination system 14 for illuminating the reticle R with an exposure light beam, and a main control unit 16 for providing general control of the entire projection exposure apparatus 10.

The wafer stage 12 comprises a first stage or XY-stage 18, which in turn comprises a Y-stage 18Y supported on a base (not shown) and movable in the Y-direction (perpendicular to the drawing sheet surface of Fig. 1) and an X-stage 18X supported on the Y-stage 18Y and movable in the X-direction (left-to-right direction as viewed in Fig. 1) perpendicular to the Y-direction. The wafer stage 12 further comprises a material support 20 carried on the X-stage 18X and movable in the Z-direction (perpendicular to the XY-plane) within a predetermined displacement range of, for example, 100 μm. The Y-stage 18Y, the X-stage 18X and the material support 20 are driven by means of a drive unit 22 for their movements in their own moving directions. The

drive unit 22 includes a pair of drive mechanisms, one for each of the Y-stage 18Y and the X-stage 18X. The drive mechanism comprises a combination of a feed screw and an electric motor for rotating the feed screw. The drive unit 22 further includes a third drive mechanism (not shown) associated with the material support 20 for driving it to move or displace in the Z-direction. The material support 20 and the associated drive mechanism together constitute a Z-stage for driving or displacing the wafer W on the material support 20 in the Z-direction. The drive mechanism associated with the material support 20 includes a built-in encoder for measuring the displacement of the material support 20 in the Z-direction, and the drive unit 22 uses the measured values output from the encoder when it drives the material support 20 in the Z-direction.

A pair of movable mirrors 24 (only one of them is shown in Fig. 1) are fixedly mounted on the material support 20. A pair of corresponding position-measuring devices or laser interferometer units 26 (again only one of them is shown in Fig. 1) are disposed each facing the associated one of the movable mirrors 24 for emitting a measuring beam (laser beam) toward the associated movable mirror 24 and using the reflection beam therefrom to measure the position of the material support 20 in the direction along its measuring beam. Specifically, the movable mirrors 24 include an X-direction movable mirror having its mirror surface extending perpendicular to the X-axis and a Y-direction movable mirror having its mirror surface extending perpendicular to the Y-axis. Similarly, the interferometer units 26 include an X-direction laser interferometer unit for measuring the position of the material support 20 in the X-direction and a Y-direction laser interferometer unit for measuring the position of the material support 20 in the Y-direction. However, in Fig. 1, only one movable mirror 24 and only one interferometer unit 26 are shown as representatives of the pairs. Thus, in the following description, it is assumed that the shown combination of the laser interferometer unit 26 and the movable mirror 24

provides the measurements of the two-dimensional, XY-coordinates of the position of the material support 20 with a high resolution of, for example, 0.01 μm. The measurements from the laser interferometer 26 are supplied to the main control unit 16.

A wafer holder 28 is mounted on the material support 20. The material piece or wafer W is held on the wafer holder 28 by means of vacuum suction, which may be provided, for example, by a vacuum chuck.

The illumination system 14 comprises a mercury lamp 30a serving as an illumination light source, an ellipsoidal reflector 30b, mirrors M1, M2, M3 and M4, a shutter 30c, a blind 30d, a condensor lens 30e and other elements not shown for simplicity. In operation, briefly, the mercury lamp 30a emits illumination rays, which are collected by the ellipsoidal reflector 30b into the region around the secondary focal point of the ellipsoidal reflector 30b. From the collected rays, only light of a selected wavelength for exposure purpose is passed through a suitable wavelength selector element (not shown) to form an illumination light beam, which then strikes on and is reflected by the mirror M1 into the shutter 30c. The wavelength may be selected, for example, to 364 nm where the light of i-line from the mercury lamp output should be used. When the shutter 30c is open, the illumination light beam (which is also an exposure light beam) is allowed to pass through the shutter 30c and reflected by the mirror M2 into an optical integrator (not shown) which may comprise a fly's eye lens. The illumination beam then passes through the blind 30d, is reflected by the mirror M3, passes through a relay lens system (not shown) and through the condensor lens 30e, and is again reflected by the mirror M4 to illuminate the reticle R. The optical integrator serves to improve uniformness in illuminance over the entire surface of the reticle R. The blind 30d is disposed at a position which is conjugate to the position of the pattern bearing surface of the reticle R and has an aperture which defines the outline of the illumination area produced on the surface of the

reticle R.

As described, the reticle R is held on the reticle holder (not shown). The position of the reticle R is adjustable within an XY-plane by means of an adjustor mechanism (not shown). The reticle R has a circuit pattern (not shown) drawn on the under surface thereof, which extends in a plane which will be substantially, optically conjugate to the plane of the surface of the wafer W.

The projection optical system PL is mounted on and supported by a body column (not shown) of the projection exposure apparatus 10, with its optical axis extending in the Z-direction. The projection optical system PL used in the disclosed embodiment has double-side telecentricity with a selected demagnification ratio β (which may be selected, for example, to 1/4 or 1/5). Thus, when the reticle R is illuminated with the illumination beam from the illumination system 14, with the alignment between the reticle R and the wafer W been established, a reduced image of the pattern on the reticle is projected through the projection optical system PL onto the photoresist-coated wafer W for making exposure.

A focus detection system of the oblique incidence type is disposed by the projection optical system PL and comprises a light-beam-sending unit 32 and a light-beam-receiving unit 34. The focus detection system (32, 34) serves to measure the displacement of the surface of the wafer W in the direction along the optical axis of the projection optical system PL (thus, the displacement is the out-of-focus distance.) The detection signals output from the focus detection system (32, 34) are supplied to the main control unit 16.

The main control unit 16 comprises a microcomputer (alternatively, it may comprise a minicomputer) including a central processing unit (CPU), a read-only memory (ROM), a random-access memory (RAM) and other known components. The main control unit 16 controls the position of the XY-stage while monitoring the measurements from the laser interferometers 26, performs the wafer-flatness measurement

process (described later in detail), controls the exposure operation, as well as provides other functions.

Further, with the projection exposure apparatus 10 according to the disclosed embodiment, the main control unit 16 is provided with a storage device 36 serving as storage means with a relatively great capacity. This storage device 36 is used to store the data indicative of displacement characteristic of the XY-stage in association with XY-coordinates of corresponding position of the material support, or the displacements of the material support 20 in the Z-direction corresponding to the positions of the material support 20 in the XY-plane. The values of such displacements, or the displacement data, are measured in advance in the manner described later, and stored in the storage device 36. The displacement data is read out from the storage device 36 by the CPU in the main control unit 16 and used for various measurement purposes. The displacement data may be used for the wafer-flatness measurement process, as described later, in order that the position of the material support 20 in the Z-direction should be corrected for such displacement through the drive unit 22.

Referring next to Figs. 2 to 4, one exemplified method of measuring the displacement characteristic of the XY-stage 18 to be stored in the storage device 36 will be described in detail.

The measurement of the displacement characteristic of the XY-stage 18 is conducted before the projection optical system PL and the focus detection system (32, 34) are mounted to the projection exposure apparatus 10. Fig. 2 is a schematic of the projection exposure apparatus 10, showing an implementation thereof for this measurement. It is noted that the illumination system 14 has been already mounted to the projection exposure apparatus 10, but is not shown in Fig. 2 for simplicity.

As shown in Fig. 2, a reference mirror 38 is placed on the material support 20 instead of the wafer holder 28 with a wafer W thereon (Fig. 1). The reference mirror 38 comprises a plane-parallel surface-mirror having very high

flatness of surfaces and with the upper surface thereof formed as a mirror surface. A distance-measuring laser interferometer unit 40 is disposed above the reference mirror 38 at a position which will be later occupied by the projection optical system PL. The laser interferometer unit 40 serves to measure the position in the Z-direction, and thus is referred to as the "Z-direction interferometer unit" hereinafter. The Z-direction interferometer unit 40 is mounted on the body column (not shown) through a fixture tool 42, with its measuring direction set in the Z-direction. The measurements output from the Z-direction interferometer unit 40 are supplied to the main control unit 16.

In order to measure the displacement characteristic of the XY-stage 18, the CPU in the main control unit 16 follows predetermined routines programmed and stored in the ROM so as to drive the XY-stage 18 along with the material support 20 through the drive unit 22 to cause two-dimensional movement of the material support 18 in the X-direction and/or Y-direction. In the two-dimensional movement of the XY-stage 18 (and thus of the material support 20), the XY-stage 18 is moved with predetermined step intervals in the XY-plane such that the material support 20 is sequentially positioned to a number of predetermined measurement points arranged in a rectangular array or matrix. For the positioning of the material support 20 to the measurement points the CPU monitors the measurements output from the laser interferometers 26, while it also measures the displacement of the material support 20 in the Z-direction in relation to its two-dimensional position in the XY-plane. Accordingly, the main control unit 16 reads the measured value output from the Z-direction interferometer 40 when the material support 20 is positioned at each measurement point and stores the measured value (indicative of the distance in the Z-direction from a reference pint) in the storage device 36 in association with XY-coordinates of the corresponding position of the material support 20 indicated by the outputs of the laser interferometers 26.

When the above measurement process is completed, displacement data has been obtained comprising the values of rise/sink of the material support 20 as caused by movement of the XY-stage 18 (and thus of the material support 20) and corresponding to the positions of the measurement points. Typical rise/sink of the material support 20 thus causes is schematically shown in Fig. 3 with exaggeration, together with the projection lens PL. An example of the rectangular array or matrix of the measurement points are shown in Fig. 4 in which intersections between broken lines are the predetermined measurement points. The displacement data indicative of the displacements of the material support 20 in the Z-direction that correspond to respective positions of the material support 20 in the XY-plane, which would also correspond to the predetermined measurement points, is stored in the storage device 36 in association with the XY-coordinates of the corresponding positions of the material support 20. The data may be stored in any appropriate form, such as a look-up table.

The solid-line curves in Fig. 4 visually illustrate, by way of example, how the rise/sink of the XY-stage 18 would be measured through the above measurement process.

The displacement characteristic of the XY-stage 18 can be measured more exactly if the distance between two adjacent measurement points (indicated as intersections between broken lines in Fig. 4) is reduced to increase the number of the measurement points. This may require, however, a longer time to complete the measurement process for acquisition of the displacement data, which may be possibly disadvantageous.

In order to avoid an unacceptable increase in the number of the measurement points, it is preferable that the main control unit 16 should perform arithmetic operation on the measured values in the displacement data obtained at a limited number of measurement points, by interpolating between measured values at adjacent measurement points using an appropriate interpolation technique, such as approximate functional interpolation, linear interpolation and spline

interpolation, so that displacement values of the material support 20 in the Z-direction for the additional points in the XY-plane distributed over the entire moving range of the XY-stage 18 may be derived. Then, the values thus derived can be stored in the storage device 36 in association with the coordinates of the corresponding positions of the material support 20 in the XY-plane. In this manner, displacement data approximating the actual rise/sink of the XY-stage 18, such as shown in Fig. 4 by solid-line curves, may be obtained without consuming a long time for the measurement process for acquisition of displacement data.

It is further preferable that the irregularities in the shape of the nominally flat top surface of the reference mirror 38 are measured through an appropriate surface shape measuring means, such as a Fizeau interferometer, before the measurement process for acquisition of the displacement data. Then, the displacement values, whether measured or derived by interpolation, are corrected for the measured irregularities (by subtracting/adding the irregularity values from/to the displacement values for the corresponding XY-coordinates) before the displacement data is stored in the storage device 36. More specifically, this may be preferably performed by placing the reference mirror 38 on the material mirror 20 as would be in the process of the measurement for displacement data acquisition, using a Fizeau interferometer to conduct the measurement process for acquisition of the data indicative of the irregularities in the surface shape of the reference mirror 38 (or surface-shape data), and storing this surface-shape data either in the storage device 36 or in appropriate storage locations in the RAM in association with the XY-coordinates of the measurement points from an arbitrarily chosen reference point.

Referring again to Fig. 1, the operation steps for the wafer-flatness measurement process conducted with the projection exposure apparatus 10 of the disclosed embodiment having the above-described arrangement will be described in detail.

As with the measurement process for displacement data acquisition (i.e., for the displacement characteristic of the XY-stage 18), the CPU in the main control unit 16 follows predetermined routines programmed and stored in the ROM so as to drive the XY-stage 18 along with the material support 20 through the drive unit 22 to cause two-dimensional movement of the material support 18 in the X-direction and/or Y-direction. In the two-dimensional movement of the XY-stage 18 (and thus of the material support 20), the XY-stage 18 is moved with predetermined step intervals in the XY-plane such that the material support 20 is sequentially positioned to a number of predetermined measurement points arranged in a rectangular array or matrix. For the positioning of the material support 20 to the measurement points the CPU monitors the measurements output from the laser interferometers 26. Further, the main control unit 16 reads the measured value output from the focus detection system (32, 34) when the material support 20 is positioned at each measurement point. Before reading the measured value, the main control unit 16 retrieve the displacement value corresponding to that measurement point (or corresponding to the current position of the material support 20 indicated in terms of XY-coordinates, as seen from the current measured values output from the laser interferometers 26) contained in the displacement characteristic of the stage (or the data of displacement in the Z-direction) stored in the storage device 36. The retrieved displacement value is used as the correction amount, such that the drive unit 22 is so controlled as to adjust the position of the material support 20 in the Z-direction to correct for the displacement, and thereby prevent the rise/sink of the XY-stage 18 from affecting the position of the material support 20 in the Z-direction. In order to retrieve from the storage device 36 the displacement value in the displacement characteristic of the stage that corresponds to the measured values output from the laser interferom ters 26, the main control unit 16 may use any suitable retrieval technique. For example,

appropriate equations showing the relation between the storage locations for displacement values and the XY-coordinates of the positions corresponding to the displacement values may be used. Alternatively, an appropriate look-up table may be used to narrow the area of storage locations to be scanned for retrieval of the desired displacement value. Further, any other quick retrieval techniques may be also used.

After the retrieved value is used to adjust the position of the material support 20 in the Z-direction, the main control unit 16 reads the measured value (or the defocus signal) output from the focus detection system (32, 34) and store it in the storage device 36 in association with the corresponding measured values output from the laser interferometers 26.

In this manner, accurate wafer-flatness data obtained at the measurement points and without any influence of rise/sink of the XY-stage 18, is stored in the storage device 36 in association with the XY-coordinates of the corresponding measurement points in an appropriate form, such as a look-up table.

If the predetermined measurement points for the wafer-flatness measurement are denser than those for the measurement for the displacement characteristic of the stage, the material support 20 will be positioned in the process of the wafer-flatness measurement to such positions for which the displacement data in the storage device 36 contains no displacement value of the material support 20 in the Z-direction. In this case, the main control unit 16 derives the displacement value corresponding to the XY-coordinates of such position, through a real-time arithmetic operation, from the displacement values corresponding to the measurement points adjacent to such position. The arithmetic operation may utilize an appropriate interpolation technique, such as approximate functional interpolation, linear interpolation and spline interpolation. Then, the displacement value thus derived is used as the correction amount, such that the drive unit 22 is so controlled as to adjust the position of

the material support 20 in the Z-direction to correct for the displacement, and thereby prevent the rise/sink of the XY-stage 18 from affecting the position of the material support 20 in the Z-direction.

As will be clearly understood from the above description, in the disclosed embodiment, the stage apparatus of the present invention comprises the wafer stage 12, the movable mirrors 24, the laser interferometers 26, the drive unit 22, the main control unit 16 and the storage device 36. The main control unit 16 constitutes an arithmetic operation device, while the combination of the drive unit 22 and the main control unit 16 constitute an adjustor for adjusting the position of the XY-stage 18 and/or the material support 20.

As described above, with the projection exposure apparatus 10 according to the disclosed embodiment, any displacement (or rise/ sink) of the material support 20 in the Z-direction as caused by the movement of the XY-stage 18 (and thus of the material support 20) in the X-direction and/or the Y-direction, due to irregularities in the nominally flat guiding surface for the XY-stage or other causes, may be corrected for based on the data in the storage device 36 when the XY-stage 18 (and the material support 20) is moved. Therefore, when the wafer-flatness measurement process is performed, the wafer-flatness may be measured by the focus detection system (32, 34) after the necessary correction to the position of the material support 20 at each measurement point, so that the wafer-flatness can be measured with higher accuracy. This effectively allows to meet severer precision requirements for accuracy in the wafer-flatness measurement, which are expected with respect to future microminiaturization of semiconductor devices.

The disclosed embodiment has been described specifically with reference to the wafer-flatness measurement; however, the application of the present invention is not limited thereto. In fact, the stage apparatus of the present invention may be used to improve measurement accuracy in any of the measurement processes in which the

positions of the moving stage are used as the reference for the measurement. For example, in the measurement process where the results of a test exposure are used to measure any of various aberrations with the projection optical system (such as variation in depth of focus, curvature of image plane, tilt of image plane and others), the stage apparatus of the present invention may be used to adjust the position of the wafer surface in the direction along the optical axis of the projection optical system, so as to improve the measurement accuracy. Thus, the stage apparatus of the present invention may be advantageously used with lens inspection equipment, implemented as a projection optical apparatus, to which a projection optical system may be detachably attached.

Further, the stage apparatus of the present invention may be desirably used with a pattern inspection apparatus in which the coordinates of the position of a pattern formed on a reticle are measured using the positions of the moving stage as the reference for the measurement. In addition, it may be desirably used with a laser beam machining apparatus for repairing defective memory chips by breaking fusible links therein to replace defective circuit elements with redundant circuit elements.

Although in the disclosed embodiment the X-stage and the Y-stage are driven through the drive mechanisms having mechanical connections and including a feed screw engaging the corresponding stage and an electric motor for rotating the feed screw, any other types of drive mechanisms may be used as well, including those having nonmechanical connections. For example, a drive mechanism of noncontact type and thus having no mechanical connection at all may be used. One example of such noncontact-type drive mechanism uses a pair of air guides running on respective rails mounted on a base, and the Y-stage (or alternatively the X-stage) is mounted on the air guides and driven by a stepping motor. Further, a linear motor may be used in place of the stepping motor. When a linear motor is used for this purpose, the linear motor may comprise a number of solenoids

mounted on the base and arranged in line along the rails for the air guides, and permanent magnets mounted on the air guides and disposed to face the solenoids. Any arrangements for driving the X- and Y-stages to move in the X- and Y-directions, respectively, may be also used, and such arrangements may include other types of noncontact-type driving mechanisms.

Wafers are sometimes finished with chemical mechanical planarization and/or chemical mechanical polishing so as to have surfaces of very high flatness. When such a wafer with highly flattened or planarized surfaces is measured for its flatness, it is expected that the wafer surface would prove itself to be a completely flat and uniform surface. However, there may be possibly foreign bodies such as dust particles between the under surface of the wafer and the top surface of the stage, so that nonuniformity in the wafer surface may be indicated by the results of the flatness measurement. This means that performing the flatness measurement on a highly flattened wafer may indicate any foreign bodies between that wafer and the underlying stage. Thus, in the case where some foreign bodies have adhered to the under surface of a wafer or the top surface of the stage during wafer changes with the stage, the presence of such foreign bodies may be checked during the wafer-flatness measurement process performed prior to the exposure process on that wafer. If the presence of such foreign bodies is actually indicated, they can be removed before the exposure process. Accordingly, a stable exposure process without any influence of foreign bodies may be ensured thereby.

In addition, while the disclosed embodiment has been specifically described with reference to the stage for carrying a wafer thereon used in an exposure apparatus of the step-and-repeat type, the present invention may be also used with an exposure apparatus of any scanning type, in which both a reticle stage carrying a reticle and a wafer stage carrying a wafer are moved in synchronism for making a scanning projection exposure for transferring the pattern formed on the reticle onto the wafer. When used with such

an exposure apparatus, the present invention may be applied to the wafer stage as with the disclosed embodiment, as well as to the reticle stage.

In the disclosed embodiment, the data stored in the storage device and/or the data derived therefrom through arithmetic operation using an interpolation technique, is used to perform the real-time adjustment (or correction) operation to adjust (or correct) the position of the material support in the Z-direction prior to each reading of the measured value during the measurement process. Alternatively, as commonly done, the wafer-flatness measurement or other measurement processes may be completed to obtain all the measured values and then correction may be effected to the measured values based on the displacement data stored in the storage device. In this manner, the wafer-flatness measurement may be performed with high accuracy as well.

As apparent from the above, the present invention provides an excellent advantage that the measurement accuracy may be improved in various measurement processes in which the positions of the moving stage are used as the reference for the measurement.

The stage apparatus of the present invention may further comprise an adjustor for adjusting, while the first stage is moved, the position of the material support in the direction along the first axis, depending on the amount of such displacement of the material support in the direction along the first axis that is indicated by the displacement data and that corresponds to the current position of the material support. Such a stage apparatus provides not only the above advantages but also the capability of correcting for rise/sink of the stage during a measurement process.

The stage apparatus of the present invention may further comprise an arithmetic operation device for performing interpolation on the displacement data in the storage to derive the amount of such displacement of the material support in the direction along the first axis that corresponds to the current position of the material support,

when the first stage has been moved to such a position for which the displacement data in the storage contains no indication of displacement. Such stage apparatus may further improve the measurement accuracy for various measurement processes in which the positions of the moving stage is used as the reference for the measurement.

The stage apparatus of the present invention may be provided for a projection optical apparatus, in which a master matrix of a pattern is illuminated with an exposure light beam so that an image of the pattern on the master matrix is projected through an projection optical system onto a photosensitized substrate. In this case, the stage apparatus may be used as a stage for positioning a photosensitized substrate, so that various measurement processes using the positions of the moving stage as the reference for the measurement, such as the flatness measurement of a photosensitized substrate, may be performed with improved accuracy.

Having described the present invention with reference to preferred embodiments thereof, it is to be understood that the present invention is not limited to the disclosed embodiments, but may be embodied in various other forms without departing from the spirit and the scope of the present invention as defined by the appended claims.

The entire disclosure of Japanese Patent Application No. HEI 8-353269 (353269/1996) filed on December 16, 1996 including specification, claims, drawings and summary is incorporated herein by reference in its entirety.

WHAT IS CLAIMED IS:

1. A stage apparatus comprising:

a first stage movable in two orthogonal directions in a predetermined plane;

a material support mounted on said first stage and capable of minute displacement in the direction along a first axis perpendicular to said predetermined plane;

a measuring device which measures coordinates of the position of said material support mounted on said first stage in said two orthogonal directions; and

a storage which stores displacement data indicative of displacement of said material support in the direction along said first axis, as caused by movement of said first stage, in association with coordinates of corresponding position of said material support.

2. A stage apparatus according to claim 1, wherein:

said displacement data stored in said storage is derived by arithmetic operation from distance data indicative of distance of a surface of a plane-parallel surface-mirror placed on said material support from a predetermined reference point, as measured in the direction along said first axis at each of measurement points while said first stage is moved with step intervals in said predetermined plane.

3. A stage apparatus according to claim 1, further comprising:

an adjustor which adjusts, while said first stage is moved, the position of said material support in the direction along said first axis, depending on the amount of such displacement of said material support in the direction along said first axis that is indicated by said displacement data and that corresponds to the current position of said material support.

4. A stage apparatus according to claim 1, further comprising:

an arithmetic operation device for performing interpolation on said displacement data in said storage to derive the amount of such displacement of said material

support in the direction along said first axis that corresponds to the current position of said material support, when said first stage has been moved to such a position for which said displacement data in said storage contains no indication of displacement.

5. A projection optical apparatus comprising:

a stage apparatus which supports a substrate;

a mask having a pattern formed thereon;

an illumination system which illuminates said mask with an exposure light beam; and

a projection optical system which projects said pattern formed on said mask onto said substrate with said exposure light beam,

said stage apparatus having:

a first stage movable in two orthogonal directions in a predetermined plane;

a material support which supports a substrate, said material support being mounted on said first stage and capable of minute displacement in the direction along a first axis perpendicular to said predetermined plane;

a measuring device which measures coordinates of the position of said material support mounted on said first stage in said two orthogonal directions; and

a storage which stores displacement data indicative of displacement of said material support in the direction along said first axis, as caused by movement of said first stage, in association with coordinates of corresponding position of said material support.

6. A stage apparatus comprising:

a stage;

a driver which drives said stage for movement in a first direction in a predetermined plane; and

a second measuring device which measures displacement of said stage in a second direction perpendicular to said predetermined plane as caused by movement of said stage in said first direction.

7. A stage apparatus according to claim 6, further comprising:

a first measuring device which measures coordinate of the position of said stage in said first direction; and

a storage which stores displacement data indicative of displacement of said stage in said second direction in association with coordinate of corresponding position of said stage in said first direction, said displacement of said stage being caused by movement of said stage in said first direction.

8. A stage apparatus according to claim 7, wherein:

displacement of said stage in said second direction is derived by arithmetic operation from distance data indicative of distance of a surface of a plane-parallel mirror placed on said stage from a predetermined reference point, as measured in said second direction at each of measurement points.

9. A stage apparatus according to claim 7, further comprising:

an adjustor which adjusts, while said stage is moved in said first direction, the position of said stage in said second direction, depending on the amount of displacement of said stage in said second direction.

10. A stage apparatus according to claim 7, further comprising:

an arithmetic operation system which performs interpolation on said displacement data in said storage to derive the amount of such displacement of said stage in said second direction that corresponds to the current position of said stage in said first direction, when said stage has been moved to such a position for which said displacement data in said storage contains no indication of displacement.

11. A method of moving a stage, comprising the steps of:

moving a stage in a predetermined plane;

measuring displacement of said stage in the direction perpendicular to said predetermined plane as caused by movement of said stage in said predetermined plane; and

correcting displacement characteristic of said stage

moved in said predetermined plane based on said measured displacement.

12. A method of moving a stage, comprising the steps of:

moving a stage in two orthogonal directions in a predetermined plane, said stage having a material support mounted thereon for minute displacement in the direction along a first axis perpendicular to said predetermined plane;

measuring coordinates of the position of said material support on said stage in said two orthogonal directions;

measuring displacement of said material support in the direction along said first axis as caused by movement of said stage in said two orthogonal directions;

storing in a storage said measured displacement in association with coordinates of corresponding position of said material support in said two orthogonal directions.

13. An exposure apparatus comprising:

a stage apparatus which supports a photosensitized substrate placed thereon;

a mask having a pattern formed thereon;

an illumination system which illuminates said mask with an exposure light beam; and

a projection optical system which projects said pattern of said mask onto said photosensitized substrate with said exposure light beam,

said stage apparatus comprising:

a stage;

a driver which drives said stage for movement in a first direction in a predetermined plane; and

a second measuring device which measures displacement of said stage in a second direction perpendicular to said predetermined plane.

14. An exposure apparatus according to claim 13, further comprising:

a first measuring device which measures coordinate of the position of said stage in said first direction; and

a storage coupled to said first measuring device and

said second measuring device,

said storage storing displacement of said stage in said second direction in association with coordinate of corresponding position of said stage in said first direction, said displacement of said stage being caused by movement of said stage in said first direction.

15. An exposure method, comprising the steps of:

moving a stage in a predetermined plane, said stage supporting a photosensitized substrate placed thereon;

measuring displacement of said stage in the direction perpendicular to said predetermined plane as caused by movement of said stage in said predetermined plane; and

controlling the position of said stage in the direction perpendicular to said predetermined plane based on said measured displacement, for making a projection of a pattern formed on a mask onto said photosensitized substrate with an exposure light beam.

16. An exposure method according to claim 15, further comprising the steps of:

measuring coordinates of the position of said stage in said predetermined plane; and

storing in a storage said measured coordinates and said measured displacement in association with each other.

17. An exposure method according to claim 15, further comprising the step of:

adjusting the position of said stage in the direction perpendicular to said predetermined plane based on said measured displacement of said stage in the direction perpendicular to said predetermined plane, when said stage is moved in said predetermined plane.

STAGE APPARATUS AND PROJECTION OPTICAL APPARATUS

ABSTRACT OF THE DISCLOSURE

When a material support is moved along with a stage, coordinates of the position of the material support are measured by a measuring device. Displacement of the material support in the Z-direction as caused by the movement of the stage is stored in the storage in association with coordinates of corresponding position of the material support. When the flatness measurement is performed on a material piece placed on the material support while the stage is moved, the amount of such displacement of the material support in the Z-direction that is indicated by the displacement data in the storage and corresponds to the current position of the material support at each measurement point, may be read out from the storage and used as correction amount for correcting the position of the material support in the Z-direction. In this manner, the flatness measurement may be performed with the correction thus effected.

Fig. 1

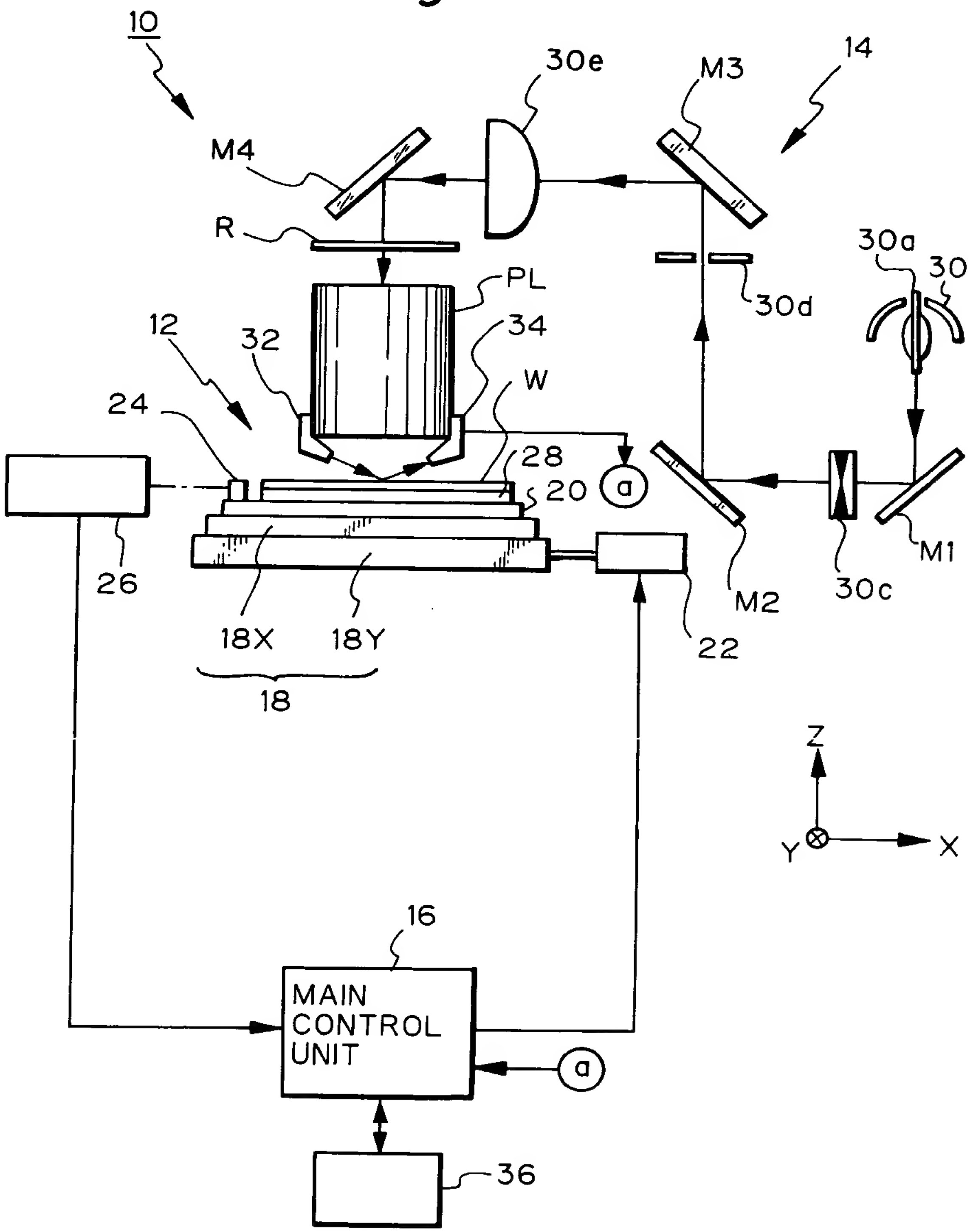
10
30e
M3
14
M4
R
30a
30b
PL
30d
12
32
34
W
24
28
20
a
M1
26
18X
18Y
22
M2
30c
18
Z
Y
X
16
MAIN
CONTROL
UNIT
a
36

Fig. 2

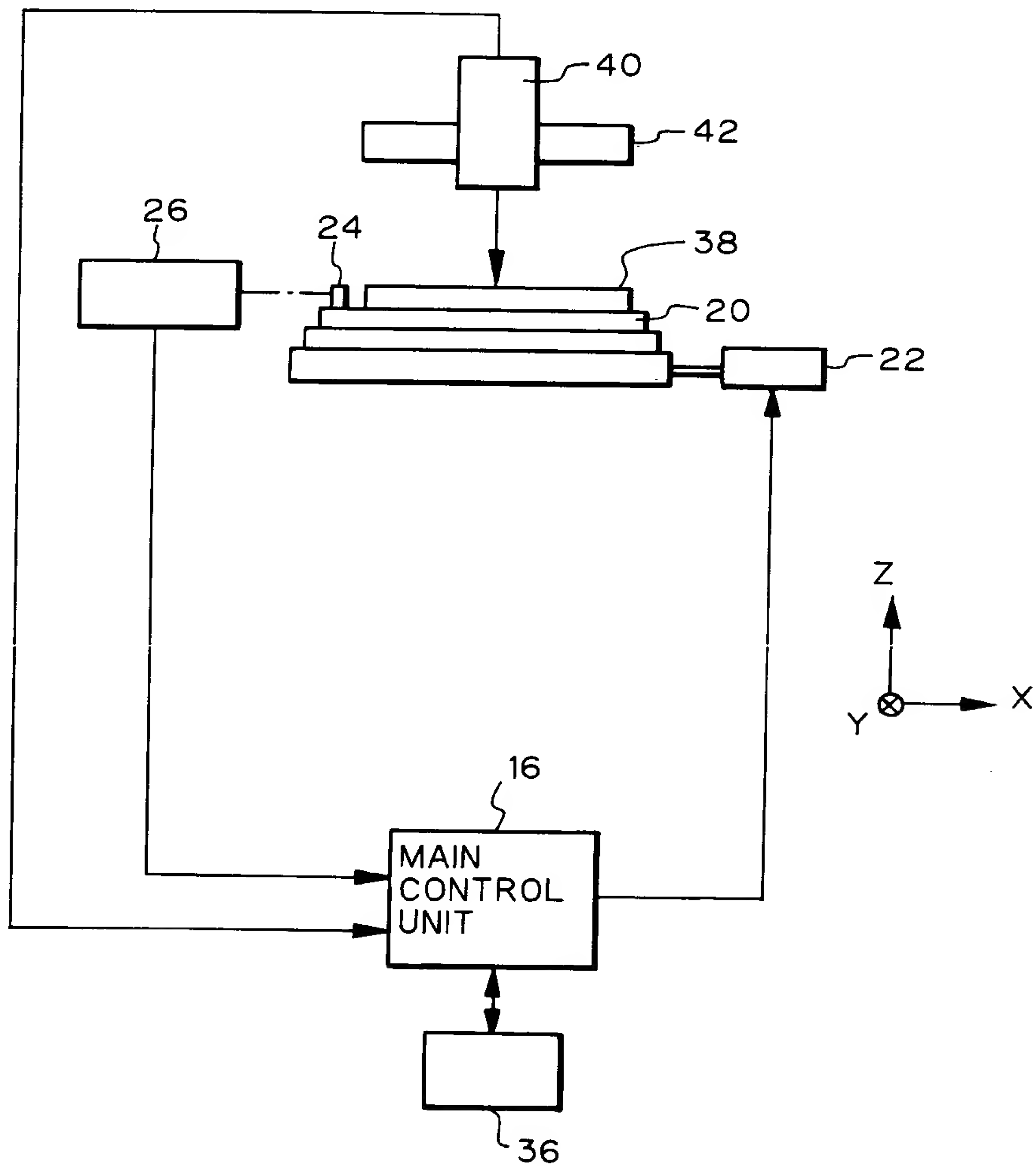

Fig. 3

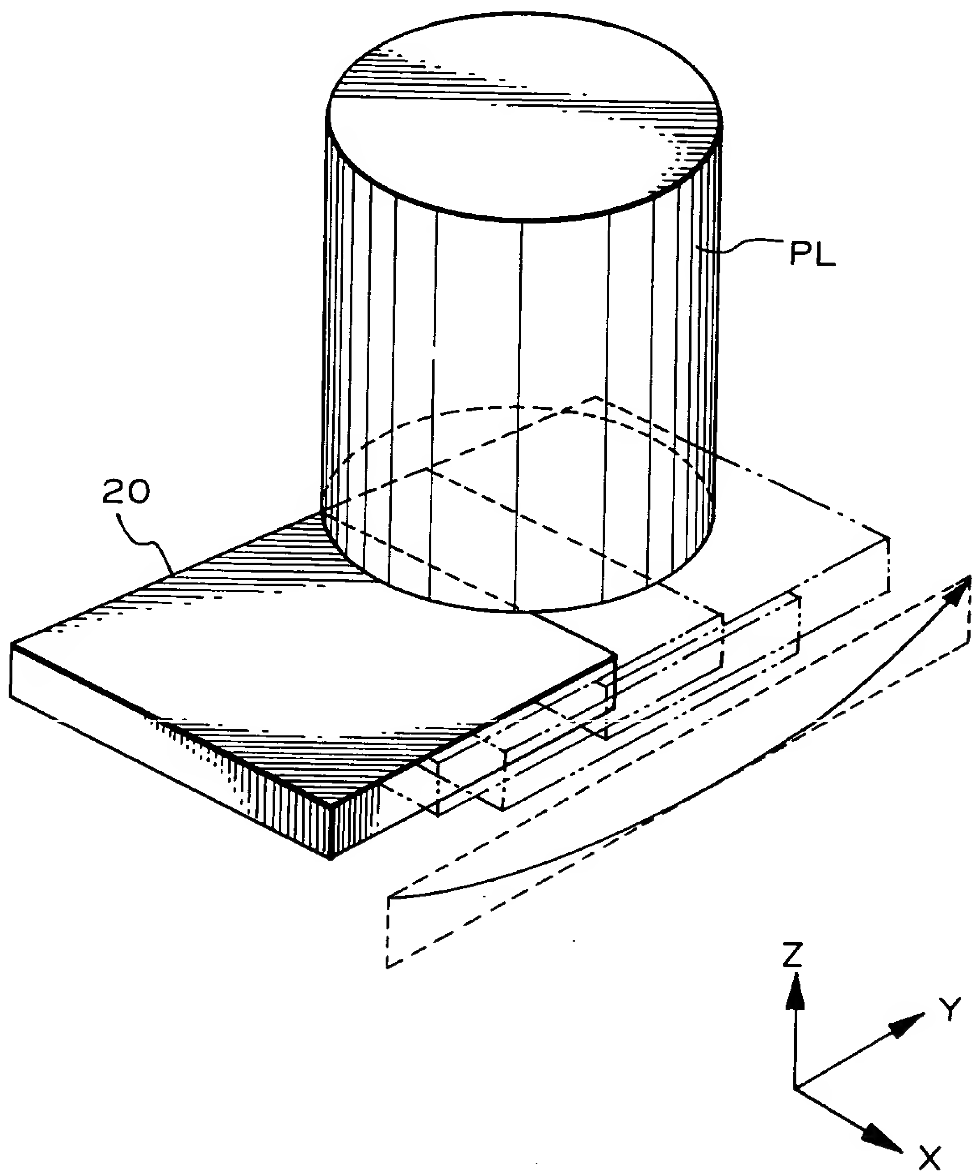

Fig. 4